LEAD INDUSTRIES ASSOCIATION
292 MADISON AVENUE
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September 30, 1960

SUBJECT: CONTINUOUS EXTRUSION OF LEAD ALLOY CABLE SHEATH

To Members of the Lead Industries Association:

Attached is a preprint of a paper to be presented at the fall general meeting of the American Institute of Electrical Engineers at the Morrison Hotel, Chicago, Illinois, on October 10, 1960.

This paper represents the successful conclusion of the research program initiated by the Cable Sheathing Task Group of the Lead Industries Association several years ago in cooperation with the John Robertson Company, manufacturer of lead extrusion presses.

The purpose of the research was to develop a continuous extrusion press which could successfully extrude the alloys commonly used for cable sheathing in this country and thus help to produce better and more economical cable.

The research project was originated by the Lead Industries Association in May, 1958, and carried to conclusion by the LIA Expanded Research Program.

The LIA has purchased sufficient copies of this preprint to circulate it to the proper engineers among cable producing and consuming companies. Additional copies may be obtained from LIA by members at 50 cents per copy as long as our supply lasts.

Very truly yours,

Robert L. Ziegfeld

Secretary

RLZ:JRH

Att.

Transactions Paper

(Reviewed and Accepted for Publication)

DEVELOPMENT OF A CONTINUOUS EXTRUSION MACHINE FOR SHEATHING CABLE WITH LEAD ALLOYS

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INTRODUCTION

Lead hardly needs an introduction as cable sheathing material. It has been widely used as sheathing for overhead and underground cable since well before the turn of the century. Among the recommendations for it are many of the characteristics which are fundamental to good cable performance.

While nearly pure lead (alloys containing only a little silver or copper) is widely used for sheath, better properties are often obtained by alloying it with other metals in small percentages. Thus, nearly all of the lead sheath used in telephone service is an antimonial alloy; much of the lead sheath used for power cable is an arsenical alloy. In the conventional methods of producing cable, however, there are some problems in producing sheaths of these lead alloys with higher percentages of secondary constituents.

To appreciate this, one must look into the methods of fabrication. One common method uses the intermittent extrusion press. In this press molten alloy is cast into a water-jacketed cylinder and caused to solidify. Then a piston advances into the cylinder, causing plastic flow. Thus the lead is forced into a die cavity and through the annulus between the die and the cable core, which is drawn through by the extruded lead sheath.

This basically simple scheme has a number of drawbacks which, while not of major proportions individually, are often of controlling importance in specific applications.

Screw driven continuous extruders have also been used to sheath cable. Until the machines developed through this research, these have been confined to the softest lead alloys--silver-bearing lead and some types of copper-bearing lead (though not all types of screw extruders will handle even this). Most of the desirable alloys have a wide melting range (up to about 50° F) which makes attainment of a steady-state cooling-casting-extrusion balance quite precarious. Moreover, the harder solidified alloy requires so much force for extrusion that the screw cannot transmit it smoothly for any practical length of run. Attempts to extrude the alloy on these screw extruders resulted in stalling and jerkiness. Even if the sheath was produced at all it was usually unserviceable.

A problem of overwhelming importance in extruding lead alloys continuously is segregation of the alloying components. As in zone refining such materials, the solid is purer than the liquid with which it is in contact. Action of the screw advances the purer solid, leaving behind a liquid containing more of the alloy component than the solid contains. Under extreme conditions regions have been found which are more than ten times richer in this component than the starting material. Even fairly short runs have produced dross-like or metallic accumulations on the screw and other parts of conventional screw extruders used to make some alloy sheaths.

Thus it can be seen that there is room for improvement in the process of producing lead sheath. It is also obvious that while a continuous screw extruder would seem to overcome the drawbacks of the intermittent press, until now it has had shortcomings of its own which have made it altogether impractical for producing the most desirable lead alloy sheaths. This paper is concerned with the research which resulted in a successful continuous extrusion machine for these lead alloys.

DEFINING THE PROBLEM

As early as five years ago a task group was formed within the Lead Industries Association to look into ways of improving lead sheathed cable. It was apparent that alloys existed which would provide better creep strength and high tensile strength. But it was also evident that none of these alloys was entirely suitable for continuous or intermittent extrusion.

Therefore, the task group undertook two types of research:

First, to find better alloys and alternate lead materials for such uses. Four projects in this direction are still active or already successfully completed.

Second, research to develop a continuous extrusion machine capable of working existing higher alloys of lead. A program similar to this had been under consideration by the John Robertson Company of Brooklyn, N. Y. Work on the development, therefore, was undertaken as a joint effort of LIA and Robertson.

DEVELOPING THE EXTRUDER

There are two principal types of continuous screw extrusion machines. They are conveniently described as horizontal and vertical screw machines. The vertical screw machine was selected as the most promising for this research.

The conventional vertical screw extruder has this general plan (Fig. 1): Lead alloy is melted in a kettle which will hold 9,000 pounds of lead. In the kettle it passes two baffle plates which prevent dross from passing through the connection pipe which feeds the extruder proper. Molten lead flows through the horizontal connection pipe and enters the lower end of the screw chamber. Just above the entrance the lead alloy solidifies. Vertical grooves or flutes in the inner wall of the screw chamber prevent the solid lead tube from rotating while the flight of the screw causes it to move upwards (in plastic flow) as the screw is rotated. Emerging from the top of the screw chamber the lead flows into a die head where the stream is split to flow past both sides of a mandrel to rejoin at the top, forming a continuous tube. At this point the configuration of the die head forces the lead alloy to make a right angle turn, flowing now horizontally. The cable core is surrounded by the lead tube and carried along by it.

Electric heaters and cooling water passages hold the desired temperatures at critical points along the route of the lead flow.

As has been pointed out, this type of extrusion machine is capable of producing a good quality sheath from silver-bearing lead and some grades of copper-bearing lead. As early as 1951 it was tried on F-3 arsenical alloy but after a short run slippage and stalling occurred, due, probably, to segregation.

In order to do a smooth job with F-3 and the other desirable alloys a complete revision of the temperature control system was made. Not only was a great deal of heating and cooling capacity added to that of the conventional machine, but it was arranged so that each small surface area along the route of lead flow was brought under more accurate control.

Temperature Controls of the Extruder

Starting at the melting kettle there are two groups of electric heaters with a total heating capacity of 90 kw under the control of two thermocouples. One couple is located at and controls heat to the input end of the kettle. The second, located near the outlet, controls heating there. The outflow temperature at the kettle is confined to a narrow range by means of a temperature control instrument which switches the heating elements from delta to wye connections.

Leaving the kettle, lead flows through a connection pipe with a 2 kw bayonet heater under control of a thermocouple near the exit end of the pipe. This pipe delivers the lead to the lower end of the vertical screw chamber -- an inherently safe design since in the unlikely event of failure of the six automatic temperature controls and seven manually controlled cooling coils from this point on, molten lead could only rise to its level in the kettle which is safely below the top of the screw chamber.

The screw housing, about three feet long, is divided into three controlled heating zones. Electric heaters with a total capacity of 20 to 27 kw are carried in machined spiral grooves surrounding the housing and are controlled by three of the eight thermocouples mounted in a vertical row. In addition, there are five water cooling channels machined into the housing wall. The water flow is controlled manually according to a preset schedule by means of rotameters.

Such elaborate provisions for temperature control bespeak a difficult heat problem. Indeed, this is the case. Consider first that this extrusion machine must operate with a variety of alloys of varying melting ranges whose metallurgical properties are controlled, in part, by their cooling and solidification rates. Furthermore, the solid alloy is forced to flow past the screw and screw housing wall surfaces (approximately 5 sq. ft. in all) solely by the force exerted by the screw. Under such conditions a large part of the applied 50 hp is converted to heat by friction. Control of temperature in the screw chamber is the most critical requirement for a successful operation.

Now the lead is forced to flow into the die head itself. Here again there are two water cooling circuits and two of the three thermocouples in the head control heaters at the top and bottom of the assembly. First the lead flows over a complex mandrel which forms the inner surface of the sheath. Emerging from the end of the mandrel it passes over a core where the pipe is formed and then through a water-cooled die which regulates the thickness of the sheath. Most of the cooling in the die block is accomplished by the two lower water cooling coils under rotameter control. These remove the heat generated by friction in the die block and hold the temperature to about 450° F. Without this cooling the die block temperature would rise to about 560° F.

The die block and mandrel used in this machine are quite similar to those used in the intermittent press, although they lie in an inverted position since lead is fed from beneath rather than from above.

Alternate Dieheads

Alternate die blocks of the sizes shown can be used interchangeably on the machine to meet any maximum cable diameter up to 5 in. Required heating capacity in the die head for temperature control there depends on the size of cable to be sheathed;

LIA24339

Schedule of die block sizes and heating requirements

Cable size	Die block size	Heating required
up to 2 in. OD	7 in.	20 kw
up to 3	9	30
up to 4	11	40
up to 5	12	40

Specifications of the Machine

Development work on this extrusion machine was carried on with a 50 hp 1750 rpm motor. While this was workable, experience has shown the desirability of more power and a 75 hp motor was installed on the prototype. Proposed larger units will be powered by 100 hp motors. In steady operation, the combination of heating and driving power for extrusion of sheath on 2 in. cable will average about 120 kw.

The motor is mounted vertically beside the screw housing (Fig. 2) and drives the screw through a 70 to 1 gear reduction train. Both gears and thrust bearing are force lubricated and cooled by oil.

The prototype's screw housing was drilled and piped with water cooling circuits and flexible hose connections (Fig. 3) to permit 35 cooling combinations. As a result of this research, present commercial units are equipped with six cooling combinations which provide all of the flexibility necessary. The housing carries a liner with from 21 to 42 vertical flutes to prevent rotation of the lead by the screw. There are eight thermocouple locations in the housing and three electric heaters to be controlled from three of the thermocouples. In addition there are heating elements in the base of the housing which are also to be controlled by the thrust bearing area thermocouple.

Cooling of the screw housing is controlled by five rotameters calibrated to the nearest 0.01 gpm with a maximum flow of 0.11 gpm to govern flow of cooling water through the five cooling circuits within the housing well. Die head and die cooling are achieved by similar cooling water passages and rotameter control.

Instrumentation is divided into three parts. All temperature indicators and controllers are located on a main panel (Fig. 4). These include the following:

1. lead melting kettle -- two off-on controllers switching the heat circuits from delta to wye (90 kw capacity)
2. connection pipe -- one off-on controller for 2 kw bayonet heater
3. screw housing -- four off-on controllers with individual control of four heating zones starting below the point of introduction of the lead and extending to the top of the housing (20 to 27 kw combined)
4. die block -- two proportional controllers for separate control of top and bottom temperature of the block (capacity varies with size)

In addition there is a seven-point scanning switch for checking the temperature at other thermocouple points.

The second group of instruments is the cooling control section. This is made up of seven rotameters, each with a range of 0.01 to 0.11 gpm.

The third group of instruments measures a variety of other operating variables:

1. cable speed recorder -- 0 to 150 fpm
2. motor load -- indicating and recording ammeter
3. motor speed -- indicating and recording tachometer
4. running time recorder
5. watt-hour meter
6. associated oil and water pressure gages

PROVING THE METHOD

After the new extrusion machine had been designed and built, it was first tested with common desilverized lead (ASTM Spec B-29 -- Pig Lead), the material commonly extruded by existing "continuous" machines. In addition to allowing the mechanical operation to be checked, this provided a test of the temperature control system.

Since the operation and efficiency of this type of machine is dependent on differential cooling, in somewhat the same way as any continuous casting of metals operation, small temperature adjustments at various points can have incommensurately large effects. Continuous extrusion resembles any continuous casting of metals except that, in addition to the casting of a solid continuous ribbon, the casting must finish at a suitable hot working temperature and sufficient force must be applied to the ribbon to extrude it through a die into a tube. When operations were adjusted to a point where common lead was extruded into 2 in. diameter pipe at the comparatively rapid rate of 85 lb per minute, the machine was considered operational and the experimental work on lead alloys was commenced.

Extrusion of Arsenical (F-3) Alloy

F-3 alloy arsenical lead was the first alloy tried in the new press. Considerable experimental development of operating techniques was needed, because extrusion of the alloy was slow, erratic, and unsuccessful through the first two months. Eventually, however, a favorable combination of heating and cooling circuits was found to overcome the solidification range of the alloy, as contrasted with the sharp melting point of desilverized lead. After this progress was rapid.

Refinement of controls and experience in operation finally made it possible to stop and start the extruder at will and rapidly bring it to a steady extrusion rate of about 35 lb per minute. Faster operation was obtained at times -- as, for example, one run of 5-1/2 hours where a steady output of 52 lb per minute was recorded.

Factors limiting output appeared to be roughness or checking of the sheath surface from excessive temperature of the alloy as it came through the die. High speeds also caused slippage or momentary hesitation of the output. The excessive temperature problem was similar to the difficulty in extruding arsenical lead too fast in a hydraulic press. Thus it is not a difficulty solely attributable to the screw-type extruders.

Means of lowering of the die block temperature and development of a water cooled die had been worked out by the end of this phase. These, in turn, increased the force needed for extrusion, and increased the occurrence of slippage which overloaded the 50 hp motor drive. To check this difficulty, the press was dismantled during the experiments and the screw was examined for segregation, alloying, or pitting. Its surface was found to be clean and smooth except for one small area at about the middle of its length where a lump of alloy adhered for no apparent reason. The slippage was, therefore, judged to be caused by friction.

Provision was then made for injection of sodium stearate into the lead feed pipe where it would be carried into the screw flight as a lubricant. Injecting of a few grams of sodium stearate every 2 or 3 hours stopped the slippage. This required halting the extrusion for 10 to 15 minutes each time, however, and often resulted in the production of tiny flakes of dross-like inclusions scattered along the surface of the next 50 ft of pipe extruded. (It is possible that injection of a gram every 15 minutes without stopping could be arranged for non-stop operation.)

Extrusion of F-3 alloy was started about November 1, 1958. After almost constant extrusion up to about April 8, 1959, during which time the metal had been extruded and remelted many hundreds of times, it was thought that the metal might be dirty, so the kettle was drained and refilled with new metal. The new metal had no effect on the operation and control of the extrusion.

Samples of pipe were selected from extrusion on 12/18/58, and again on 1/30/59, analyses of which are shown in Table I. Dip samples of alloy from the 3 compartments of the electric melting kettle feeding the extruder were taken on 1/30/59. Although the kettle had not been skimmed from 11/1/58 to 1/30/59, there was no appreciable dross accumulation except about 1/16 in. on the outlet compartment, which was also sampled.

Table I

F-3 ALLOY - CHEMICAL ANALYSES

		Pipe Sample of	Pipe Sample of	Kettle Samples of 1/30/59		
Required		12/18/58	1/30/59	Melting Compartment	Middle Compartment	Outlet Compartment
0.10 to 0.20	Arsenic, %	0.127	0.140	0.132	0.133	0.130
.05 to .15	Tin, %	.097	.109	.118	.116	.105
.05 to .15	Bismuth, %	.06	.06	.06	.06	.06
.01 Max.	Antimony, %	<.005	<.005	<.005	<.005	<.005
.01 Max.	Copper, %	<.005	<.005	<.005	<.005	<.005

Table II

F-3 ALLOY - TENSILE & BEND PROPERTIES

	Tensile Strength psi	Elong. in 2.15 in. %	No. of 90° Bends IPCEA Bender
Samples of 12/18/58			
1. Pipe cut after 4 minutes extrusion @ 23 lb/min	2280	30.0	-
2. Pipe cut after 19 minutes extrusion @ 30 lb/min	2305	36.6	-
3. Pipe cut after 30 minutes extrusion @ 35 lb/min	2270	29.0	-
4. Pipe cut after 35 minutes extrusion @ 35 lb/min	2330	33.4	-
5. Pipe cut after 90 minutes extrusion @ 42 lb/min (with slight water cooling on die)	2285	39.9	39 to 55
Samples of 1/30/59			
6. Pipe cut after 38 minutes extrusion @ 36 lb/min	2283	27.1	45 to 51
7. Pipe cut after 45 minutes extrusion @ 36 lb/min	2240	27.4	41 to 51
8. Pipe cut after 60 minutes extrusion @ 36 lb/min	2180	34.4	41 to 51

NOTE: Tensile specimens were machined rings which were pulled over oval shaped pins for gripping with a cross head speed of 0.5 in. per minute.

The grain structure of ring-shaped cross sections of all the various F-3 alloy pipe samples appeared similar to that of any lead sample produced on a screw-type extruder, except for a smaller grain size. There were shadowy patterns of flow lines present in the sides of the tube wall, ending in "tongues" near the top and bottom of the section. These flow lines appear to be produced by the joining of successive flights of cast ribbon as it leaves the screw and is compressed into a solid mass in the die block. Tiny particles of oxides, which form on the surface of the ribbon as it slides up the screw, are found in some of the flow lines. (The tongue-shaped pattern is produced by flow of the lead in the die block, as it splits over the bridge and core tube and welds together again to form a pipe.) The flow lines are never severe enough to restrict grain growth across them and, therefore, should be harmless to mechanical performance of a cable sheath.

Less noticeable were the die welds caused by the die block. Streaks of patterns that could be attributed to alloy segregation in the structure were absent. Examples of F-3 alloy pipe grain structure are shown in the micrographs.

Figure 5 shows the general structure of sample #3 (Table II). The ring in the center shows a whole cross section and the micrographs show the areas to which they are tangentially mounted, at a magnification of 20 diameters. The section was etched rather deeply to bring out the flow lines and the surface got a little rough, but it shows the rather uniform grain and the lack of segregation.

Figure 6 shows the general structure of sample #8. Both these samples exhibit a high contrast well defined grain characteristic of air cooled soft F-3 alloy.

Figure 7 shows the structure of sample #5 at 250 diameters. The surface was microtomed and lightly etched for this examination, and shows the rather fine, almost indistinct grain boundaries characteristic of arsenical lead, with no film of oxide or other segregation in the grain boundaries. The scattered small black particles are some form of arsenic precipitated from solution by the slow cooling.

Figure 8 shows sample #8 after laboratory heat treatment. The appearance of the flow lines became more noticeable after heat treatment. This is not a segregation of alloying elements, but rather an agglomeration of the tiny oxide particles. All these samples were collected before the use of sodium stearate was begun.

After about 5 months of experimenting and over 150 hours of actual extrusion, during which there were some all day runs of pipe, it was felt that all difficulties were pretty well overcome. It appeared that the continuous extrusion of F-3 alloy in the new extruder was under control and would be commercially feasible. Discovery of the use of sodium stearate in tests during the latter part of this work appeared to be a big step in keeping the screw clean and maintaining steady operation.

On April 8, 1959, two 40-ft lengths of 3/C 500 MCM 15 kv solid type paper cables were sheathed. Sodium stearate was injected into the extruder, which was then brought up to a speed of 9 fpm for 8/64 in. wall 2.31 in. O.D. sheaths (32 lb/min), and the cables fed into the die block one after the other. The die block was held at 450° F and a small amount of water cooling was used on the die, but no water cooling on the cable. The extruder ran without hesitation and a smooth tight sheath was obtained. The operation appeared routine.

Results of chemical and mechanical tests on this sample are listed in Table III.

Table III

F-3 ALLOY CABLE SHEATH

Chemical Analysis		Tensile Properties	As Extruded	After Heat Treating
Arsenic, %	0.150	Ultimate Strength, psi	2,475	2,820
Tin, %	.101	Elongation, % in 3.10 in.	28.2	41.5
Bismuth, %	.10	No. of 90° Bends (with IPCEA Bend Tester)	35 to 47	17 to 33
Copper, %	.00	Concentricity, %	96.8	-

Tensile strength of the sheath was a little higher than that of the pipe, but the water cooled die did not have a quenching effect on the alloy. The sheath material responded well, however, when a sample was subsequently quenched from a suitable working temperature in the laboratory. Therefore, quenching was considered unimportant for the present experiments as suitable quenching could be provided, if desired, in a commercial installation.

Since high fatigue strength in bending is the most important characteristic of arsenical lead sheaths, a length of cable was immediately tested in the machine described by Hickernell, Jones and Snyder with the following results:

Movement Inches	Actual Strain %	Cycles to Failure	Increase in Diameter %
1-1/2	0.241	21,432	1.5
2	.390	13,618	4.3

These data compare well with the data presented in the above publication, and with subsequent data on file. The "continuously extruded" F-3 alloy cable sheath thus possessed fatigue strength similar to F-3 alloy sheath made with a hydraulic press.

The grain structure of the sheath sample was not as uniform as that of the pipe, but the same effect is experienced with sheathing extruded from a hydraulic press. The flow lines are a bit more prominent than in the pipe, perhaps because of the sodium stearate lubrication added just prior to extruding the sample. No mechanical weakness was apparent.

Although no creep test data are available, it certainly appeared that this cable sheath had the characteristic chemical, metallurgical and mechanical properties of F-3 alloy cable sheath and was a satisfactory commercial product.

Extrusion of "Habirloy" Arsenical Alloy

"Habirloy" arsenical lead alloy was then extruded into pipe with the new extruder. Since the machine operated well with nearly the same control settings as used previously with F-3 alloy, no difficulties were experienced. Both the sodium stearate lubrication and the water cooled die and die block were used during extrusion. Extrusion speed was similar to that for F-3 alloy, with perhaps slightly less power required.

A sample of pipe from this material was analyzed with the results listed in Table IV.

Table IV

HABIRLOY PIPE DATA

Chemical Analysis		Tensile Properties	
Arsenic, %	0.12	Ultimate Strength, psi	2250
Tin, %	.09	Elongation, % in 3.03 in.	36.0
Bismuth, %	.01	No. of 90° Bends (with IPCEA Bender)	39 to 47
Copper, %	.025	Concentricity, %	93.3

The grain structure of a cross section of this pipe had a characteristic appearance similar to that of F-3 alloy.

Although only about 17 hours of actual extrusion time were devoted to this alloy, the ease of operation indicated that commercial extrusion should be practical.

Extrusion of Tellurium Alloy

"Tellurium Lead" arsenical lead alloy was next extruded. The machine started easily under the same control settings as used for the other arsenical lead alloys, but more force appeared necessary to maintain extrusion and the output was not as steady as that of previous runs.

A sample of pipe from this material was analyzed, with the results listed in Table V.

Table V

TELLURIUM LEAD PIPE DATA

Chemical Analysis		Tensile Properties	
Arsenic, %	0.185	Ultimate Strength, psi	2425
Tin, %	.12	Elongation, % in 3.09 in.	41.5
Tellurium, %	.08	No. of 90° Bends (with IPCEA Bender)	23 to 49
Bismuth, %	.12	Concentricity, %	97.3
Copper, %	.00		

The grain structure of a cross section of this pipe appeared different from those of the other arsenical leads. Various methods of etching were tried but the result was the same. In addition to the usual pattern of flow lines, certain areas in the sides of the section always became pitted and darker, and dark radial bands showed at the top and bottom die welds.

It was noted that these dark areas gave somewhat lower bend test results than the lighter areas, although the average elongation on a tensile test was very good. Based on about 20 hours of actual extrusion, the machine should be able to extrude this alloy.

Extrusion of Antimonial Alloy

Antimony lead alloy was then extruded. The machine started very easily with the die block at 450° F, and its operation was very steady, but the output was lower than for the arsenical alloys with the power available. More power was definitely required for this alloy. The pipe extruded at only 25 to 28 lb per min was noticeably smoother. Whether this alloy would have given trouble with roughness at the die when extruded at 35 to 45 lb per min, as the arsenicals did, is uncertain.

A sample of pipe from this material was analyzed with the results listed in Table VI.

Table VI

ANTIMONY LEAD PIPE DATA

Chemical Analysis		Tensile Properties	
Antimony, %	0.99	Tensile Strength, psi	3155
Copper, %	.04	Elongation, % in 2.67 in.	38.1
Bismuth, %	.068	No. of 90° Bends	17 to 29
Arsenic, %	.00	Concentricity	95.8

The grain structure of a cross section of this pipe appeared different from those of the arsenical leads because of the different etching characteristics of antimony lead. It appeared that the pipe had a rather uniform grain except for the die weld areas. The flow line pattern was similar to that found in the other alloy pipes. The dark areas around the tips of the flow lines probably indicate some precipitation of antimony rather than segregation. This drastically affects the etching properties of the alloy. It may be that faster extrusion or readjustment of the cooling circuits would have overcome this.

It was noted from the bend test data that these dark areas were not as plastic as the lighter areas although the average elongation in a tensile test was good. The lower average number of bends was to be expected, of course, because of the higher strength (and hardness) of this alloy.

Although only about 10 hours actual extrusion time was spent because of lack of power, it appeared that with a 75 hp motor, this machine should be able to extrude this alloy satisfactorily in commercial operation.

Extrusion of Other Alloys

Chemical lead was then extruded with the special machine. Although this type of lead is reputedly more difficult to extrude with this type of machine than the acid-copper lead, it was extruded freely under the same operating conditions as used for the arsenical alloys. With the use of sodium stearate injections, no build-up of copper on the screw was noted in the short time of operation.

A sample of pipe from this material was analyzed with the results listed in Table VII.

Table VII

CHEMICAL LEAD PIPE DATA

Chemical Analysis		Tensile Properties	
Copper, %	0.057	Tensile Strength, psi	1930
Bismuth, %	.000	Elongation, % in 3.11 in.	30.8
Silver, %	.005	No. of 90° Bends	41 to 51
Nickel-Cobalt, %	.0034	Concentricity, %	96.2

The grain structure of a cross section of this pipe was rather uniform and showed only faintly the usual pattern of flow lines formed by the extruder.

The grain size was larger than would be expected of the alloys.

Acid copper lead was not extruded with the new machine because it is satisfactorily extruded by several cable makers with a similar vertical screw machine of conventional design in regular commercial operation. Since it was obvious that the new machine would extrude this lead alloy satisfactorily, it was not tested. A sample of the cable sheath was analyzed, however, for comparison with the other materials. These data are listed in Table VIII.

Table VIII

DATA FROM ANALYSIS OF ACID-COPPER LEAD CABLE SHEATH

Chemical Analysis		Tensile Properties	
Copper, %	0.065	Tensile Strength, psi	1805
Bismuth, %	.01	Elongation, % in 2.5 in.	35
Antimony, %	.00	No. of 90° Bends	39 to 43
Tin, %	.00	Concentricity, %	96.4

The grain structure of a cross section of this cable sheath was very uniform, but the typical pattern of flow lines formed by a screw-type extruder were present. In fact, it appeared that the flow lines were more numerous, which of course might be expected from our explanation of the cause of these markings on an etched metallographic specimen. The standard vertical screw extruder has a 12 flight screw as compared to the 9-1/2 flight screw in the special experimental machine. The joining of successive flights of cast ribbon as it leaves the screw and is compressed into a solid mass in the die block leaves welds that can be disclosed by polishing and deep etching. When these welds are free from oxides and segregation or second phase materials, they appear to have no effect on the mechanical properties of the sheath, as shown by the very uniform bend values and good elongation in tension for most of the samples.

CONCLUSIONS

The formal testing and development work on a continuous extrusion machine for all desirable lead alloys for cable sheath has been completed. The results have been satisfactory and the machine is now in commercial use. It is believed that all the fundamental problems have been adequately solved and that any future changes in the design or methods of operation will be concerned only with marginal areas such as reduction of maintenance or reducing the investment needed for continuous sheath extrusion.

In reviewing the previous difficulties of producing superior lead cable sheath the most obvious conclusion to be drawn from this work is that it is now possible to continuously extrude cable sheath of any lead alloy commonly used. Since operation is continuous, it requires a minimum of setting up and supervision. And within the normal range of industrial usage, the equipment is safe and convenient.

Since the cable is produced continuously there are no press welds or periodic changes in the sheath. Indeed, the sheath shows a remarkable uniformity both in its gross aspects and under close metallographical examination. Of primary importance is the fact that this is true of the concentricity of sheath and core. Production runs of cable to have 0.090 in. sheath have consistently tested 0.090 to 0.093 in.; in runs where a *minimum* of 0.082 in. was the specification, the results were 0.082 to 0.0831 in.

While the continuous extrusion machine has not yet been extensively used for sheathing cable employing polyethylene and other insulation which degrades at high temperature, the very fact that this unit keeps the cable moving continuously is a step towards a foolproof method of doing this.

Beyond the original goals of the program it has been found that the alloy of the sheath is much cleaner and much more free of oxides than that produced on any conventional sheathing equipment. This should mean that cable produced by this method will have an unusually good service life since there are no weak points for physical or corrosive attack. It will be several decades before sufficient data accumulate to prove this point.

CAPTIONS FOR ILLUSTRATIONS

Figure 1 -- An overall schematic of the continuous lead alloy cable sheath extrusion machine. In general plan it is similar to conventional horizontal screw machines. The principal changes have been a modified screw and screw housing, increased power, and the temperature measuring and control equipment. (The die head has been rotated through 90° in this schematic. Actually, the cable core is fed from behind the plane of the illustration and the sheathed cable emerges toward the reader.)

Figure 2 -- The continuous lead alloy sheath machine installed at the Yonkers plant of Phelps Dodge. Melting kettles are at left, the screw housing at center and the drive motor is at right.

Figure 3 -- This was the experimental set up for temperature control of the screw housing. Connections for heating, cooling, and monitoring temperature are shown. Though this elaborate control system was necessary for the research, production equipment has been considerably simplified (see Figure 2).

Figure 4 -- The control panel. At left, all temperature controllers and indicators. Rotameters and water and oil gages at center. Recorders of temperature, production rate and associated motor control equipment are at right.

Figure 5 -- A sample (#3--see text) of F-3 alloy extruded by the machine. A whole cross section of the sheath is shown with micrographs of the wall adjacent to the sections of the sheath from which they came. Note the rather uniform grain structure and absence of segregation. Actual sheath diameter is 2 in.

Figure 6 -- Another sample (#8--see text) of F-3 alloy sheath produced by the machine. Compare this with Figure 8.

Figure 7 -- A much enlarged micrograph of F-3 alloy sheath produced by the machine. The actual dimensions of the area shown are 0.013 x 0.017 in. (the micrograph was made at X250). Grain boundaries are rather fine and almost indistinct as is characteristic of arsenical lead. No oxide film or segregation is evident at these boundaries. The scattered black particles are some form of arsenic precipitated by the slow cooling.

Figure 8 -- The same sample (#8) of F-3 alloy shown in Figure 6 after laboratory heat treatment to bring out the flow lines. These lines are not due to segregation of the alloying elements but to agglomeration of oxide particles.

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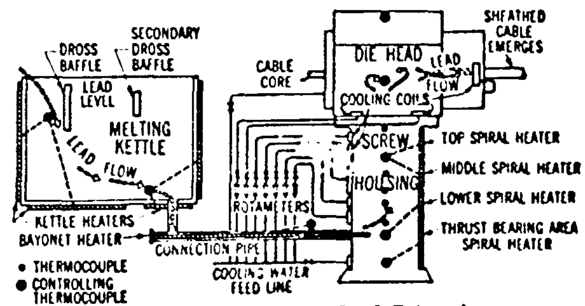

Fig. 1. Continuous Lead Extrusion Machine

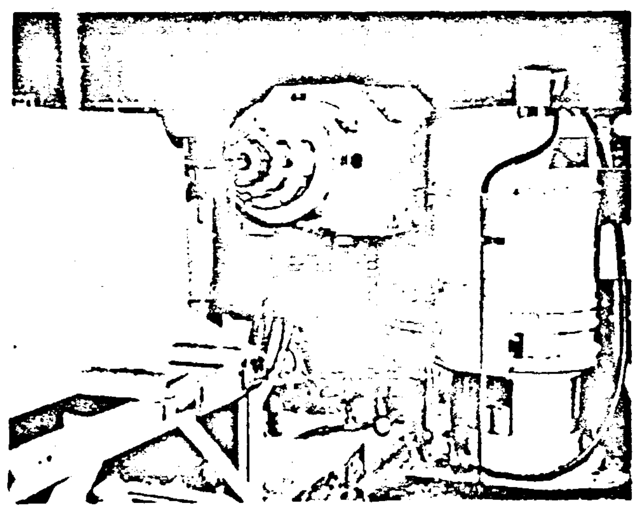

Fig. 2. Extruder as Installed

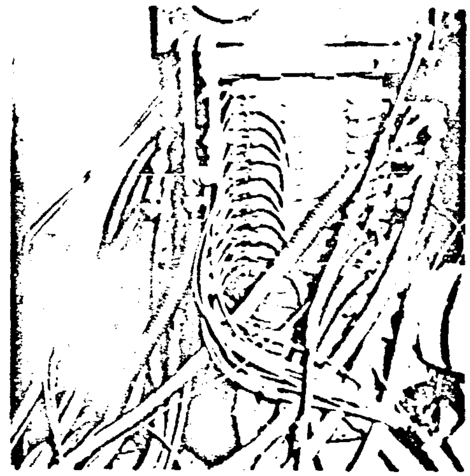

Fig. 3. Cooling and Instrumentation of Screw Housing on Pilot Unit

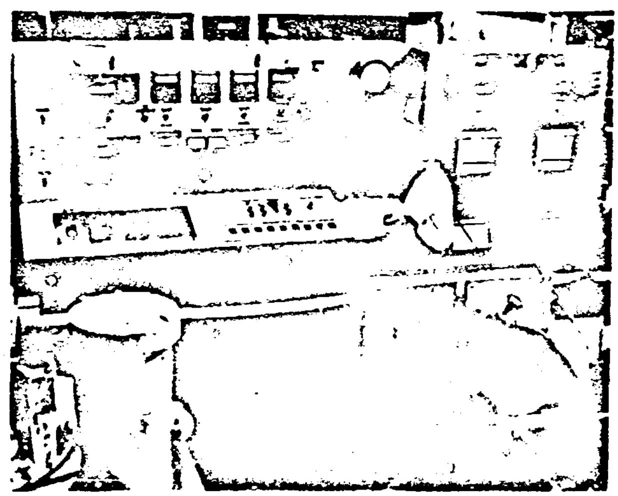

Fig. 4. Master Control Panel for Extruder

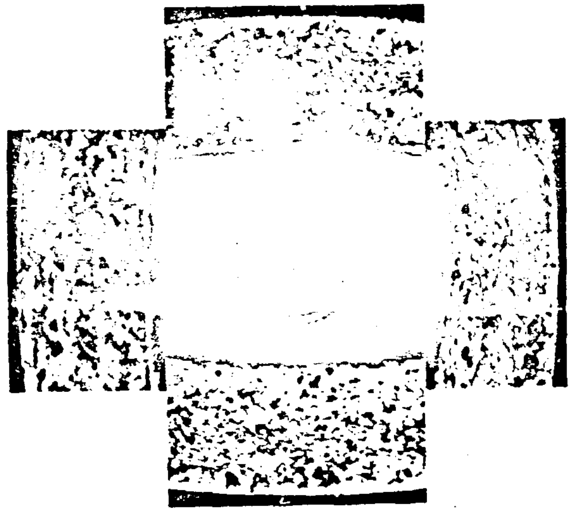

Fig. 5. Grain Structure of F-3 Alloy
2" I.D. Pipe Sample No. 3

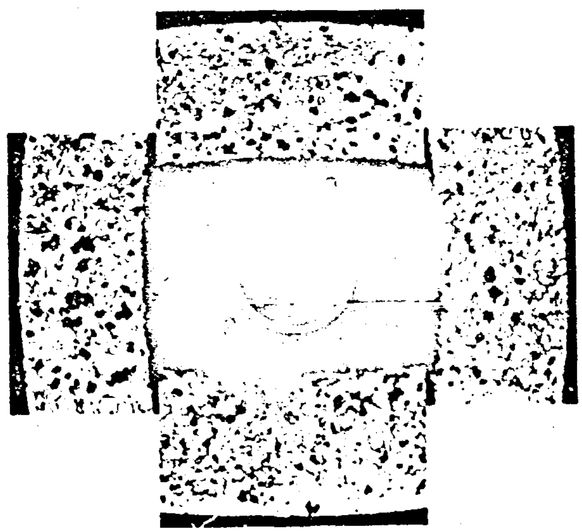

Fig. 6. Grain Structure of F-3 Alloy
Pipe Sample No. 8

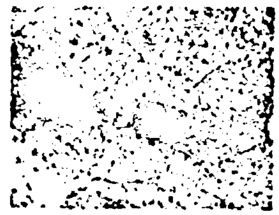

Fig. 7. Micrograph F-3 Alloy Sheath
Sample No. 5 250 X

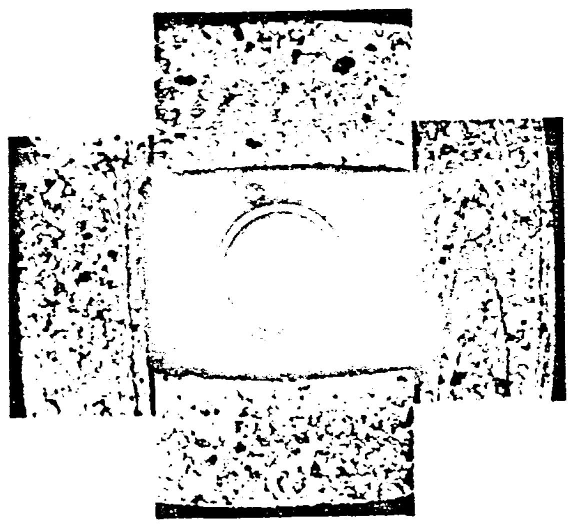

Fig. 8. Grain Structure of F-3 Sheath
Sample No. 9 After Laboratory
Heat Treatment